

HEAT ANALYSIS OF CHINESE COAL

BY

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ARMOUR INSTITUTE OF TECHNOLOGY

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Engineering analysis of
chinese coal

ENGINEERING ANALYSIS OF CHINESE COAL

A THESIS

PRESENTED BY

MUN SUN TONG

TO THE

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DESIGNATION OF SAMPLES OF COAL.

No. I. - Kwang Tung, Bak Kwang, Yung Shan Yih,
Tong Hung Shan.

No. II.- Kwang Tung, Bak Kwang, Shin Jao Sun Shan.

No.III.- Kwang Tung, Shin Jao, Ying Dok Yin,
Ngao How Shan.

No. IV.- Kwang Tung, Bak Kwang, Shin Jao, Ying
Dok Yin, Shui Hoh Shan.

No. V. - Tai Ling Won, Fu Shan Kwang.

No. VI.- Chih-li, Hui Ping Kwang.

No.VII.- Kwang Tung, Bak Kwang, Shui Jao,
Dung Shui Shan.

PROXIMATE AND HEAT ANALYSES OF CHINESE COAL.

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Introduction.

Coal, both bituminous and anthracite, is found in almost every province in China, most of it in proximity to iron, and all easily obtained. The province of Honan alone has 21,000 square miles of anthracite, a showing which compares favorably with the best anywhere. The total coal area of China has been estimated at 419,000 square miles. Coal was mined there in the Ninth Century and stored within walled cities for use as fuel in time of siege; but because of quarrels between various clans over the mines, the Emperor ordered all mines closed, and not until the last century have they been reopened. Little mining has been done until within recent years.

Various reasons have contributed to prevent the Chinese from working their mines to any depth or to any extent: first, because it was illegal, all minerals being claimed by the Emperor; second, because of the Fung-shui superstition, which warns against all tampering with the earth lest the

equilibrium of the elements be disturbed and dreadful calamities result; and third, because of the lack of engineering skill, and Western appliances which are essential to deep mining. Since the establishment of native-owned steam ship lines and railways, however, a supply of steam-coal has become necessary, and now mining is in active operation under Government auspices in different provinces.

Sometimes as many as twenty or thirty layers of coal, alternating with rock, are found, the coal ranging in thickness from many feet to less than one inch. In most of the Chinese mines the work of hauling, lifting and lowering is performed by human labor instead of by machinery. Skilled mechanics are scarce, but coolie labor is cheap and plentiful.

All coal as mined, contains more or less moisture. It is exposed to the air in shipment and may either dry out or be wet by rain. The moisture in the coal is worthless to the purchaser, and really costs him a considerable amount in freight and cartage, to say nothing of the loss of heat required for its evaporation in the furnace. This makes moisture an important element in the valuation of

a ton of coal. Earthy matter and other impurities that will not burn are classed as ash. In commercial coal the proportion of ash is 25 per cent and below, according to its value, the most valuable containing the smallest per cent of ash. Coal containing fixed carbon in a higher proportion than volatile matter is most easily burned to render the greatest number of British Thermal Units, (B.t.u.). Sulphur, iron, lime and silicon are frequently found in coal, and the presence of these minerals causes the formation of clinkers when the coal is burned. A knowledge of what the coal contains, as well as of the proportions of the elements and the heat value is of prime importance to the engineer in charge of a power plant.

The samples of coal used in this analysis were obtained from several mines in Kwang Tung Province of South China near the city of Canton, and also from Chih-li Province near Peking. The coal was shipped to Chicago in canvas bags enclosed in a tight wooden box to prevent evaporation of moisture and also to prevent absorbing moisture while on its ocean voyage.

Preparation of Samples.

The various samples of coal were taken from the canvas bags in which they were shipped and crushed by a grinding machine until fine enough to pass through a sieve of from 75 to 90 meshes per square inch. The samples were then bottled and labeled and kept air-tight in the laboratory until needed for analysis.

Balances and Weights.

The balance used in weighing the samples consists of an accurately balanced beam, having a scale pan hung at each end. A pointer which plays over a scale at the base of the supporting column is attached to the center of the beam. The column is hollow to provide for a rod which carries the main bearing at the top and is raised or lowered by an eccentric mechanism and the lever on the lower left hand side. When not in use, or when weights are placed in the pans, the eccentric mechanism lowers the bearing and allows the beam to rest on the arms which extend from the top of the column, or beam arrest, as it is called. At the ends of the beam are nuts on threaded studs which are used

to balance the beam. The entire instrument, which is covered by a glass case, stands on three adjustable screws, by which it may be leveled. The metric system of weights is used with these balances as it is the most convenient both for rapidity in weighing and calculating percentages. The gram is taken as the unit and is equivalent to 15.432 grains, or 453.6 grams equal one pound avoirdupois.

The weights are kept in a covered box, the small weights under an extra glass cover. All weights above one gram are of polished brass, cast with a knob on top. The smaller weights are made of platinum and aluminum, being flat with a loop of wire turned up on the edge to make them easily handled with the forceps, which belong with the set. All weights of one gram or more are stamped with their value in grams, while the smaller weights are stamped with their value in milligrams. The weights must always be handled with the forceps, never with the fingers.

A balance must be used with great care, as it is an instrument of precision and its value must be preserved. When the balance is used it should be placed on a solid table or shelf out of a draft and leveled by means of the eccentric lever. If the pointer swings to an equal distance each side of the center mark on the scale, the beam is properly balanced. If it does not, the heavy end will fall the lower and the pointer will swing farther toward the end of scale near the light scale pan. To correct it, the nuts at the end of the beam are screwed in or out, as the case may be, to make the arm heavier or lighter. The beam should be lowered to the supports by the lever when a balance is secured.

Desiccator and Crucible.

The desiccator is a vessel which has a compartment at the bottom containing a chemical, either sulphuric acid or calcium chloride, which has strong absorbing powers, and so keeps the air in the vessel dry. The cover of the desiccator fits with a ground glass joint which is made air tight with a coating of vaseline. When

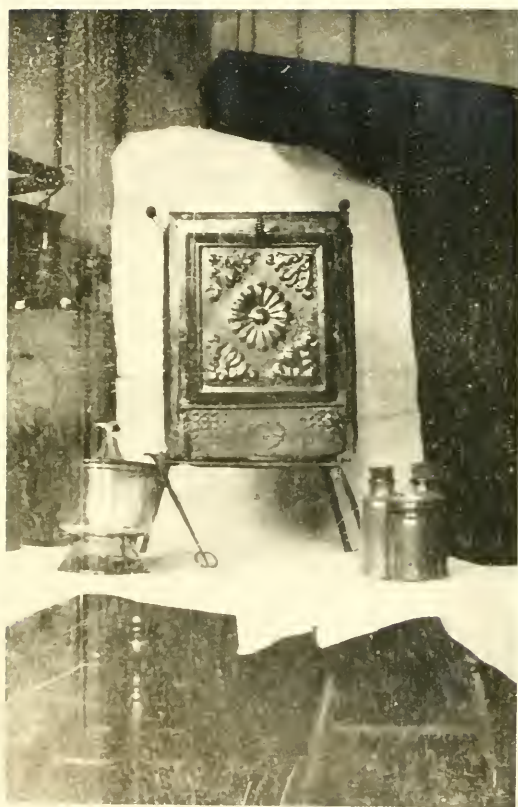


the coal sample is to be cooled it is kept in the desiccator to prevent the coal absorbing moisture before it can be weighed.

The porcelain crucible used should be thoroughly cleaned and dried and placed over a Bunsen burner in order that all foreign matter, such as oil from the fingers, etc., may be burned off. Before weighing the crucible it should be cooled as high temperature affects the weight. From the time the crucible is cleaned until the analysis is finished it should be handled entirely with forceps, as the fingers may leave marks which would affect the weight. An iron ring stand having a platinum holder in the center is used to hold the crucible over the flame.

Oven.

The oven consists of a steel plate box, standing on four legs and is placed on a table or bench. The door drops on hinges in front. In a small opening in the top is fastened a Fahrenheit thermometer which stands up above the oven so that it is easily read.



Method of Analysis.

The proximate analysis consists in the determination of moisture, ash and volatile combustible matter.

To determine the moisture in these samples of coal from China, a small amount of the pulverized sample was taken from the air-tight jar in which it had been kept and less than a gram was placed in each of two crucibles, which had been previously weighed, and marked so as to distinguish one from the other. They were then placed in the desiccator to dry. Each crucible with its portion of coal was carefully weighed and the weights recorded. The two crucibles were then placed in the oven and the Bunsen burner beneath the oven was lighted. The temperature of the oven was kept between 220° and 230° Fahrenheit. It could not be allowed to go too low lest all the moisture be not driven out, and it could not be allowed to go too high, lest some volatile matter escape. After one hour the crucibles were removed from the oven, cooled in the desiccator and weighed again. They were then returned to the oven and left for another period when they were removed and again weighed. This was repeated until

weights were found to be the same in successive weighing, which proved that they were no longer losing moisture.

In this and all tests which followed, two portions of the sample were tested in two crucibles that one might check the other. If results were proximately the same the test was good, but if they varied more than one half of one per cent new portions of sample were taken and the test repeated.

In this test for moisture of Sample No. 1, of Chinese coal, the figures were as follows:

Crucible A, empty - - - - - 3.344 grams

Crucible A, plus the coal - - - - 4.491 grams

$4.491 - 3.344 = 1.147$ grams = wt. of coal

Crucible A, plus the coal, after
one hour in the oven -- - - - 4.472 grams

$4.491 - 4.472 = 0.019$ grams loss in moisture

$0.019 \div 1.147 \times 100 = 1.65\%$ moisture

Crucible B, empty - - - - - 3.637 grams

Crucible B, plus the coal - - - - 4.592 grams

$4.592 - 3.637 = 0.955$ grams = wt. of coal

Crucible B, plus the coal, after
one hour in the oven - - - - 4.576 grams

$4.592 - 4.576 = 0.016$ grams loss in moisture

$0.016 \div 0.955 \times 100 = 1.67\%$ moisture.



Ash, as determined by the proximate analysis, is much the same, chemically, as the refuse found in the ash pit of a furnace. However, there is this important difference. In making an ash determination in the laboratory, all the combustible matter contained in the coal is burned and the manner of combustion does not permit clinkering. The two crucibles, after being weighed, marked and dried in the desiccator, were each filled with less than one gram of the powdered coal samples, and then weighed again. They were then placed in the platinum holder of the ring stand, over a lighted Bunsen burner, and left uncovered until the contents appeared entirely white. The crucibles were then removed, cooled in the desiccator and then weighed. They were then returned to the flame and burned for another half hour and again weighed after being cooled in the desiccator. When successive weighings were the same it showed that all combustible and volatile matter had been burned and nothing but ash remained.

The result of the ash test of Sample No. 1, was as follows:

Crucible A, empty - - - - - 8.146 grams

Crucible A, plus the coal - - - - 9.554 grams

$9.554 - 8.146 = 1.408$ grams = wt. of coal

Crucible A, plus the coal, after
two hours and 22 minutes over
the flame - - - - - 8.361 grams

$8.361 - 8.146 = 0.215$ grams = wt. of ash

$0.215 \div 1.408 \times 100 = 1.52\%$ ash.

Crucible B, empty - - - - - 8.082 grams

Crucible B, plus the coal - - - - 9.493 grams

$9.493 - 8.082 = 1.411$ grams = wt. of coal

Crucible B, plus the coal, after
two hours and 22 minutes over
the flame - - - - - 8.301 grams

$8.301 - 8.082 = 0.219$ grams = wt. of ash

$0.219 \div 1.411 \times 100 = 1.55\%$ of ash.

Volatile Combustible Test.

The volatile combustible matter is that which distills from the dried coal at the lower temperature in the furnace in the form of gas which is combustible and is composed almost entirely of hydrogen and carbon in varying proportions, known as hydro-carbon. In testing Sample 1 for volatile combustible matter the crucibles were marked, weighed

and dried and then filled with the powdered coal, less than one gram in each. The crucibles were tightly covered and weighed before being placed over the Bunsen burners on ring stands with aluminum holders. When the crucibles became hot, the hydro-carbon gases were driven out from under the cover and burned. When these gases ceased to burn the crucibles were left over the flame for another five minutes to make sure that all the volatile matter had been driven off, when they were cooled in the desiccator and weighed. The crucibles were left covered and were returned to the flame for another five minutes, then cooled and weighed as before. When the loss in weight from the last heating amounted to less than five grams the preceding weight was taken.

The results of this test on Sample 1 were as follows:

Crucible A, with cover, empty - - - - 17.328 grams

Crucible A, with cover, plus the coal 17.713 grams

$17.713 - 17.328 = 0.385 \text{ grams} = \text{wt. of coal}$

Crucible A, with cover, plus the coal
after 20 minutes over the flame - - 17.678 grams

$17.713 - 17.678 = 0.035 \text{ grams} = \text{volatile combustibile matter}$
 $0.035 \div 0.385 \times 100 = 9.1\% \text{ volatile combustibile matter.}$

Sample	Moisture	Check	Volatile Matter	Check	Ash	Check	Combustible Matter	Check	B. t. u.	Check
1	1.857	1.675	9.1	9.05	15.2	15.5	74.043	73.775	12,563	12,616
2	1.13	1.11	9.54	9.59	16.71	16.53	72.62	72.79	12,257	12,362
3	1.46	1.39	6.54	6.51	41.61	41.05	50.39	51.15	4,872	4,768
4	1.52	1.508	5.57	5.61	46.1	46.4	46.61	46.782	4,716	4,845
5	3.44	3.29	6.25	6.31	41.2	42.4	48.11	48.00	13,550	13,212
6	0.57	0.58	17.53	17.91	23.11	23.01	58.69	58.5	12,429	12,339
7	0.561	0.559	7.97	8.05	14.61	14.38	76.859	77.011	11,943	11,993

Crucible B, with cover, empty - - - - - 19.401 grams

Crucible B, with cover, plus the coal - - 20.241 grams

$$20.241 - 19.401 = 0.84 \text{ gram} = \text{wt. of coal}$$

Crucible B, with cover, plus the coal

after 20 minutes over the flame - - - 20.165 grams

$$20.241 - 20.165 = 0.076 \text{ gram} = \text{volatile combustible matter.}$$

$$0.076 \div 0.84 \times 100 = 9.05\% \text{ volatile combustible matter.}$$

The Calorific Value of Coal
by the Use of the Mahler Bomb Calorimeter.

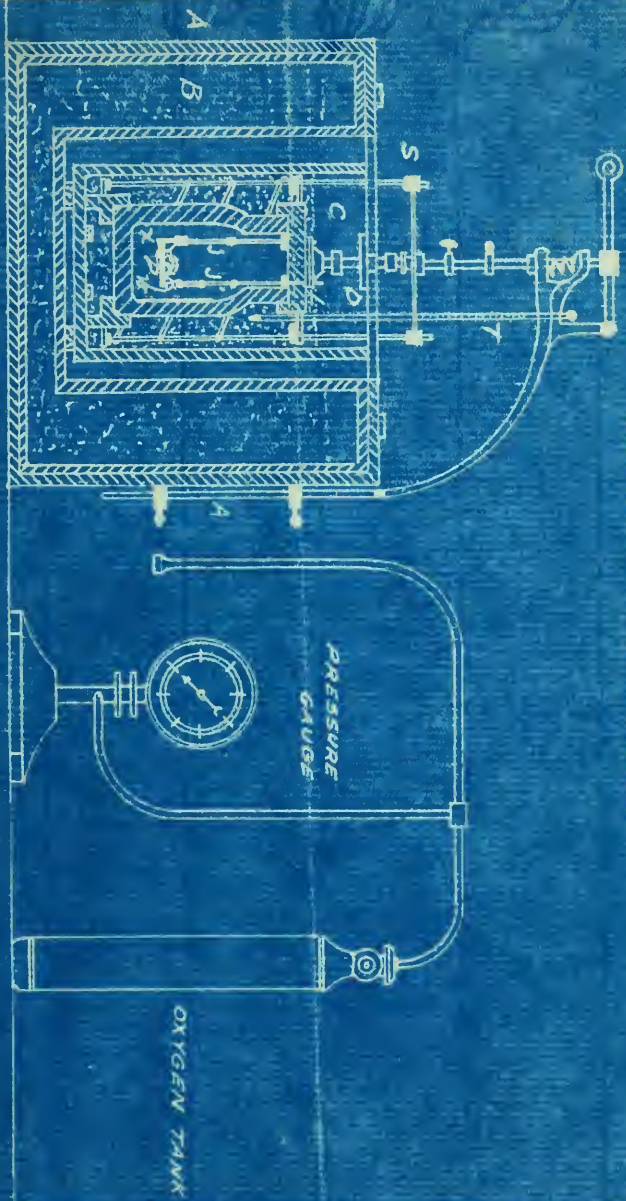
In order to determine the calorific value of a fuel, conditions must be such that the heat evolved may be absorbed and measured, and also that combustion be perfect. To provide these conditions several instruments have been designed, the principle feature of most of them being that the heat evolved is allowed to act on a given quantity of water, causing an increase in temperature thereto. The heat given up by the fuel then is equal to the weight of water plus the water equivalent of the instrument multiplied by the rise in temperature. Perhaps the most satisfactory calorimeter of this type is the one known as the Mahler bomb calorimeter, which differs but slightly from the idea of the original designer, M. Berthelot.

The Mahler bomb calorimeter consists of a nickel plated receptacle (C) which is placed within the water filled vessel (B). (A) shows the water jacket surrounding the whole apparatus, to reduce loss by radiation, and keep conditions constant. (S) is a stirrer which agitates the water in (B) and (T) measures the temperature of the water. The bomb itself is shown in the upper part of the figure. (X) shows a cross section of the vessel, which is porcelain lined. The plug (L) screws into the top of this vessel making a water tight joint. The legs (J) and (J') which project from the plug are connected to terminals of an electric circuit, and the iron wire (W), which connects these two legs, passes through the sample of coal in the pan (P), which is hung from a peg on one of the legs. Oxygen may be introduced into this vessel through the plug, the valve knob (D) controlling an opening for this purpose. The pan containing the coal was first weighed empty and then with the sample of coal. The pan was then placed in position on the plug and the plug screwed tightly into the bomb. Oxygen was now introduced until a pressure of about twenty atmospheres was

reached, when the oxygen inlet was tightly closed, the oxygen tank disconnected and the bomb placed in the copper vessel (B), which was filled with water. The water in this vessel was stirred constantly, and readings taken from the Beckman thermometer, the bulb of which was inserted in the water. Readings were taken every half minute through a magnifying glass held vertically in order to avoid a parallax. These readings were taken for a period of five minutes in order to obtain the rate of radiation before combustion took place. The electric circuit was now closed, which fused the thin iron wire and ignited the coal. Readings were continued at half minute intervals till a maximum temperature was reached. Readings were continued for five minutes after the maximum temperature had been reached in order to determine the rate of radiation at the higher temperature. The rate of radiation at intermediate points is assumed to be on a straight line connecting these two points when the determined radiations have been plotted to scale.

A curve of the whole run may be plotted, using time as abscissas and temperature as ordinates. The

MAHLER BOMB CALORIMETER



rate of radiation for the different points may be found on the radiation curve and cumulatively added at each point. That is, the radiation correction made at the second point would be that of the first point, plus that of the second; the correction at the third point would be the sum of the radiation at the first, second and third points, and so on for every point to the end of the run. This gives a new curve which runs off straight at the highest point. The true temperature difference then is the difference between the point of ignition and the straight point of the corrected curve, and it is this difference which is used in the calculations.

The amount of water in the calorimeter must be determined before the run and the water equivalent of the calorimeter must be known. With this knowledge, however, the calculations are simple. The grams of water, plus water equivalent of the calorimeter, multiplied by the true temperature rise, gives the calories given up to the water and calorimeter, and hence the heat given up by the fuel. This divided by the weight of the sample gives the calories given up per gram. All the units used so far, have been of

the metric system, the Bechman thermometer being also calibrated in the centigrade scale.

To change calories per gram to B.t.u. per pound requires the introduction of a constant factor, which is 1.8.

Ratio of B.t.u. per pound to calories per gram:

$$1 \text{ pound} = 2205.8 \text{ grams}$$

$$1 \text{ B.t.u.} = 1 \text{ pound raised } 1^{\circ} \text{ F. or } 1.8^{\circ} \text{ C.}$$

$$= 2205.8 \text{ grams raised } 9/5^{\circ} \text{ C.}$$

$$\text{B.t.u. per pound} = 2205.8(9/5) \quad 2205.8$$

$$= 1.8 \text{ calories per gram.}$$

CALCULATIONS FOR CALORIFIC VALUE.

Sample I.

Test No. 1.

Weight of pan - - - - - 6.107 grams

Weight of pan, plus sample - - 6.506 grams

Weight of sample - - - - - 0.399 grams

Rate of radiation at ignition temperature =

$$(2.10 - 2.08) \div 10 = 0.002^{\circ} \text{ per half minute.}$$

Rate of radiation at maximum temperature =

$$(3.09 - 3.045) \div 10 = 0.0045^{\circ} \text{ per half minute.}$$

Recorded rise of temperature =

$$3.09 - 2.08 = 1.01^{\circ}$$

Radiation correction = 0.025°

True rise of temperature = $1.01 + 0.025 = 1.035^{\circ}$

Water in calorimeter = 2200 c.c.

Water equivalent of calorimeter = 512 c.c.

Total water equivalent = 2712 c.c.

Heat given up to water and calorimeter =

$$2712 (1.035) = 2806.9 \text{ calories}$$

Heat given up per gram of coal =

$$2806.9 \div 0.399 = 7034.9 \text{ calories}$$

B.t.u. given up per pound of coal =

$$7034.9 (1.8) = 12663$$

Sample I.

Test No. 2.

Weight of pan - - - - - 6.107 grams

Weight of pan, plus the sample - 6.658 grams

Weight of sample -- - - - 0.551 grams

Rate of radiation at ignition temperature =

$$(2.00 - 1.98) \div 10 = 0.002^{\circ} \text{ per half minute}$$

Rate of radiation at maximum temperature =

$$(3.36 - 3.31) \div 8 = 0.0063^{\circ} \text{ per half minute.}$$

Recorded rise of temperature =

$$3.36 - 1.98 = 1.38$$

Radiation correction = 0.044

True rise of temperature = 1.424

Water in calorimeter = 2200 c.c.

Water equivalent of calorimeter = 512 c.c.

Total water equivalent = 2712 c.c.

Heat given up to water and calorimeter =

$$2712(1.424) = 3590.7 \text{ calories}$$

Heat given up per gram of coal =

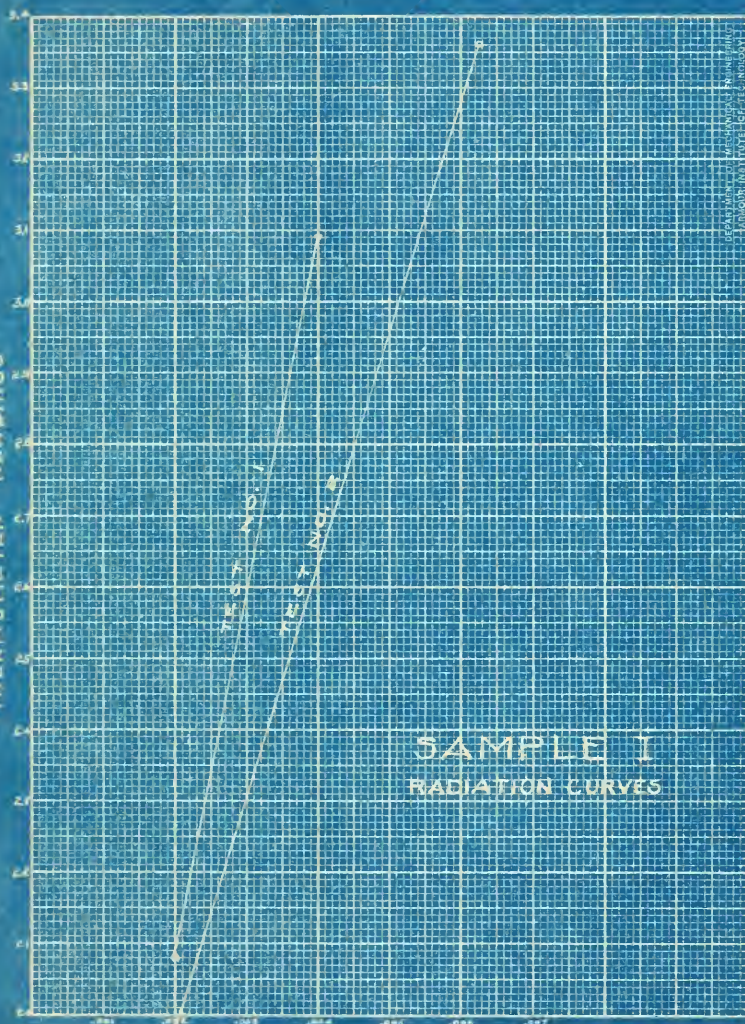
$$3590.7 \div 0.551 = 7008.8$$

B.t.u. given up per pound of coal =

$$7008.8(1.8) = 12616$$

Average value = 12640 B.t.u. per pound.

THERMOMETER READINGS

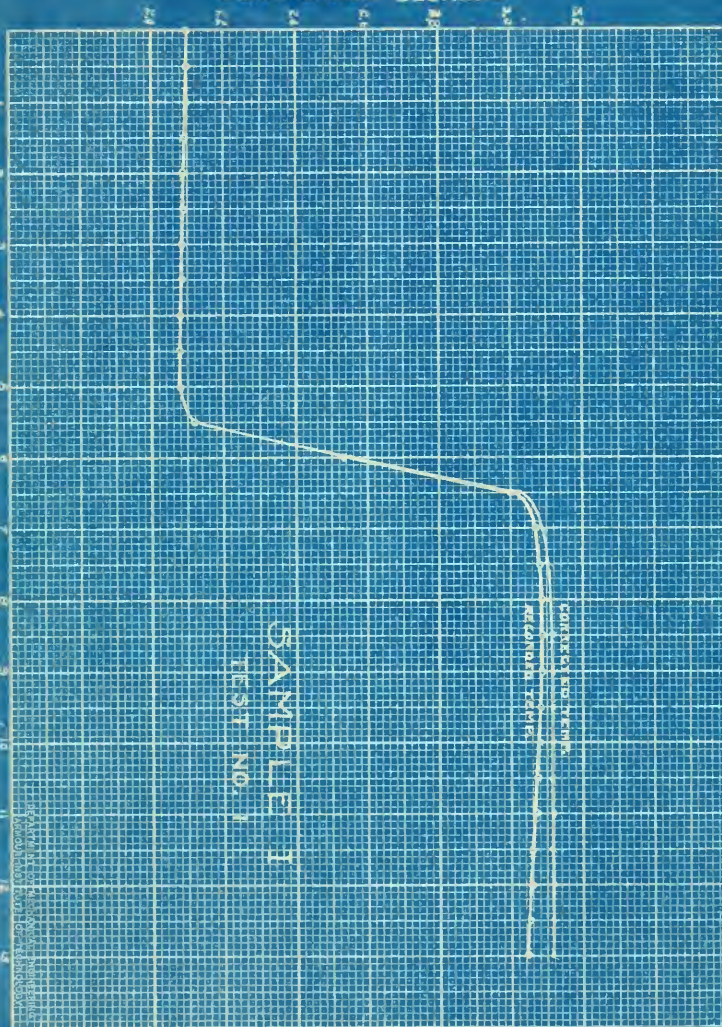
SAMPLE I
RADIATION CURVES

RATE OF RADIATION - DEGREES PER 1/2 MIN.

LEGALIZED BY MECHANICAL REPRODUCTION
BY THE U.S. GOVERNMENT

CENTIGRADE DEGREES

TIME - MINUTES



SAMPLE NO. 1
TEST NO. 1

TEMPERATURE
IN DEGREES
CENTIGRADE

TIME IN MINUTES

SAMPLE I.

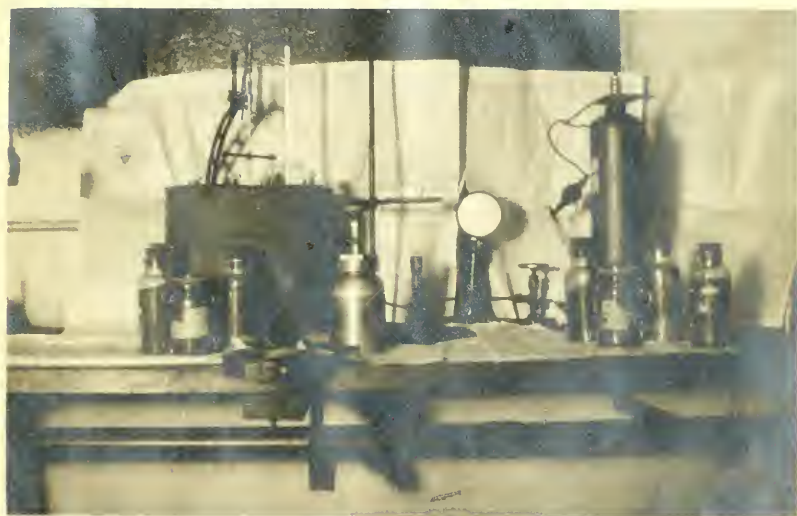
Test No. 1.

	Recorded Temperature, Degs.C.	Radiation, Degrees Per Half Minute	Radiation Correction Degs. C.
	0	2.10	
	0.5	2.10	
	1.0	2.10	
	1.5	2.095	
	2.0	2.09	
	2.5	2.09	
	3.0	2.085	
	3.5	2.085	
	4.0	2.08	
	4.5	2.08	
Ignited-	5.0	2.08	
	5.5	2.12	0.0021
	6.0	2.63	0.0031
	6.5	3.00	0.0038
	7.0	3.07	0.0039
	7.5	3.085	0.0040
	8.0	3.09	0.0040
	8.5	3.09	0.0040
	9.0	3.088	0.0040
	9.5	3.082	0.0040
	10.0	3.080	0.0040
	10.5	3.072	0.0039
	11.0	3.070	0.0039
	11.5	3.060	0.0039
	12.0	3.060	0.0039
	12.5	3.055	0.0039
	13.0	3.050	0.0039
	13.5	3.045	0.0039

SAMPLE I.

Test No. 2.

Time, Minutes	Recorded	Radiation,	Radiation
	Temperature Degs.C.	Degrees Per Half Minute	Correction Degs. C.
0	2.00		
0.5	2.00		
1.0	2.00		
1.5	1.995		
2.0	1.992		
2.5	1.99		
3.0	1.99		
3.5	1.988		
4.0	1.985		
4.5	1.98		
Ignited- 5.0	1.98		
5.5	2.00	0.002	0.002
6.0	2.92	0.005	0.007
6.5	3.27	0.006	0.013
7.0	3.34	0.0062	0.0192
7.5	3.36	0.0063	0.0255
8.0	3.36	0.0063	0.0318
8.5	3.36	0.0063	0.0381
9.0	3.36	0.0063	0.0444
9.5	3.35	0.0063	0.0507
10.0	3.345	0.0063	0.0570
10.5	3.34	0.0062	0.0632
11.0	3.335	0.0062	0.0694
11.5	3.328	0.0062	0.0756
12.0	3.32	0.0062	0.0817
12.5	3.315	0.0062	0.0879
13.0	3.310	0.0062	0.0941



SOURCE OF ERROR.

These seven samples of Chinese coal differed greatly, varying from hard coal to lignite. The slight errors made in the tests may have arisen from any one or more of the following causes:

Vibrations of the building, caused by passing trains on the nearby railroad, or by the engine in the school building, may have caused an error in the use of the balance. In the moisture tests some of the volatile matter may have been driven out in the oven. In the readings of the thermometer the magnifying glass might have been held carelessly, causing a parallax. When the oxygen was introduced into the bomb calorimeter from the oxygen tank, the valve may have been opened too suddenly, causing the oxygen to blow off some of the powdered coal from the pan. During the time required for each test the temperature of the room should have been constant in order to secure accurate results. It is possible that there may have been some fluctuation in the temperature, causing error in radiation. If the outer vessel containing the water surrounding the bomb was not kept filled to a certain height some error in radiation may have resulted. Some mistake in measuring the

2200 c.c. of water in the inner vessel might be made. For each test this water should be remeasured to avoid error, as the amount does not remain exactly the same from one test to the next. In conducting the test for calorific value if the water used is not allowed to stand for at least 24 hours in the room, so as to be of the same temperature as the room, error in radiation is the result. At the conclusion of the bomb test when the bomb is removed from the inner vessel of water, if any drops of water are allowed to fall into the empty space between the inner vessel and outer vessel, error in radiation is the result.

